Spacecraft Systems

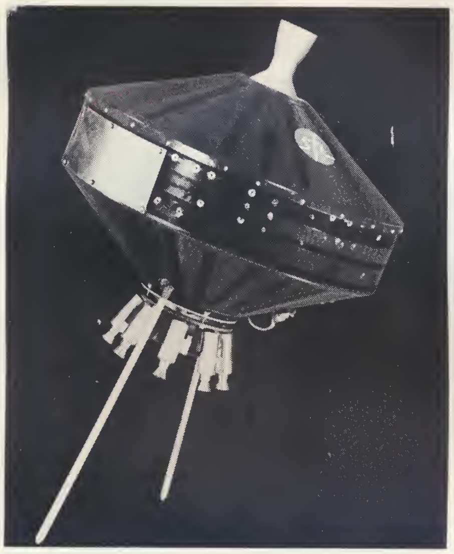
TRW SYSTEMS

Since 1957, TRW Systems has participated in nearly every United States space launching and project — either as a prime contractor or supplier of subsystems and services. Many of the nation's early spacecraft, including Pioneer I, Explorer VI, and Pioneer V, were designed and built by TRW and launched by boosters the company had systems engineered for our country's ballistic missile program.

Today, TRW has prime responsibility for the design and manufacture of Orbiting Geophysical Observatories, Nuclear Detection Satellites, a new series of Pioneer deep-space vehicles, Global Communications Satellites, and Environmental Research Satellites. Its personnel are involved in the development of multi-purpose satellites and advanced spacecraft systems for scientific explorations of Mars, Venus, and the outermost regions of the solar system.

This brochure briefly describes some of TRW's contributions to the space program . . . the company's advanced work in preparing for future space missions . . . and the depth and breadth of its technological base.

Pioneer I

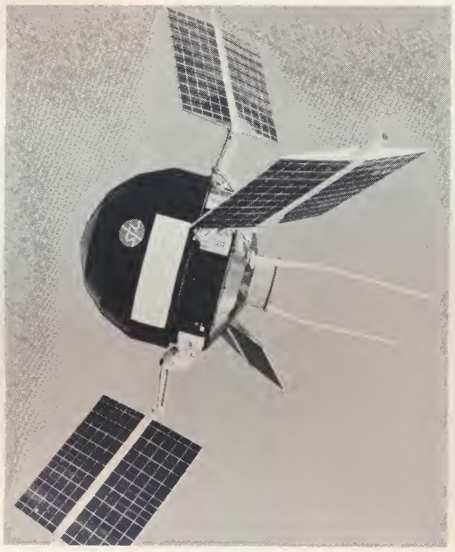


TRW's experience as a producer of spacecraft dates back to 1958, when its personnel designed and fabricated Pioneer I, NASA's first spacecraft. Pioneer I was also the first spacecraft produced by a privately-owned firm.

Launched in October 1958, Pioneer I carried a payload of scientific instruments to an altitude of 70,700 miles—by far the deepest penetration of space until that date. Small and unsophisticated compared to present-day spacecraft, Pioneer I made important contributions to the knowledge of spacecraft technology, including the successful operation of scientific instrumentation in space, telemetry-tracking-command systems, and vernier velocity correction rockets.

The 84-pound probe passed completely through the Van Allen region and provided the first sure knowledge of how far beyond the earth this region of radiation extends. Pioneer I also provided the first accurate observations of the earth's magnetic field, the interplanetary magnetic field, and micrometeoroids at extremely high altitudes.

Explorer VI



Explorer VI was the first of a series of versatile "paddlewheel" satellites designed and produced for NASA by TRW Systems. It was also the first spacecraft equipped with a modern photovoltaic electric power system—one incorporating both solar panels and rechargeable secondary batteries.

In August 1959, Explorer VI was launched into a highly elliptical orbit (perigee, 157 miles; apogee, 26,366 miles) which allowed its experiments to investigate space phenomena at a wide variety of altitudes. In addition to providing a wealth of new information about the ionosphere, magnetic fields, the Van Allen region, and solar radiation, Explorer VI carried an image-transmission system which relayed the first television photograph of the earth from outer space.

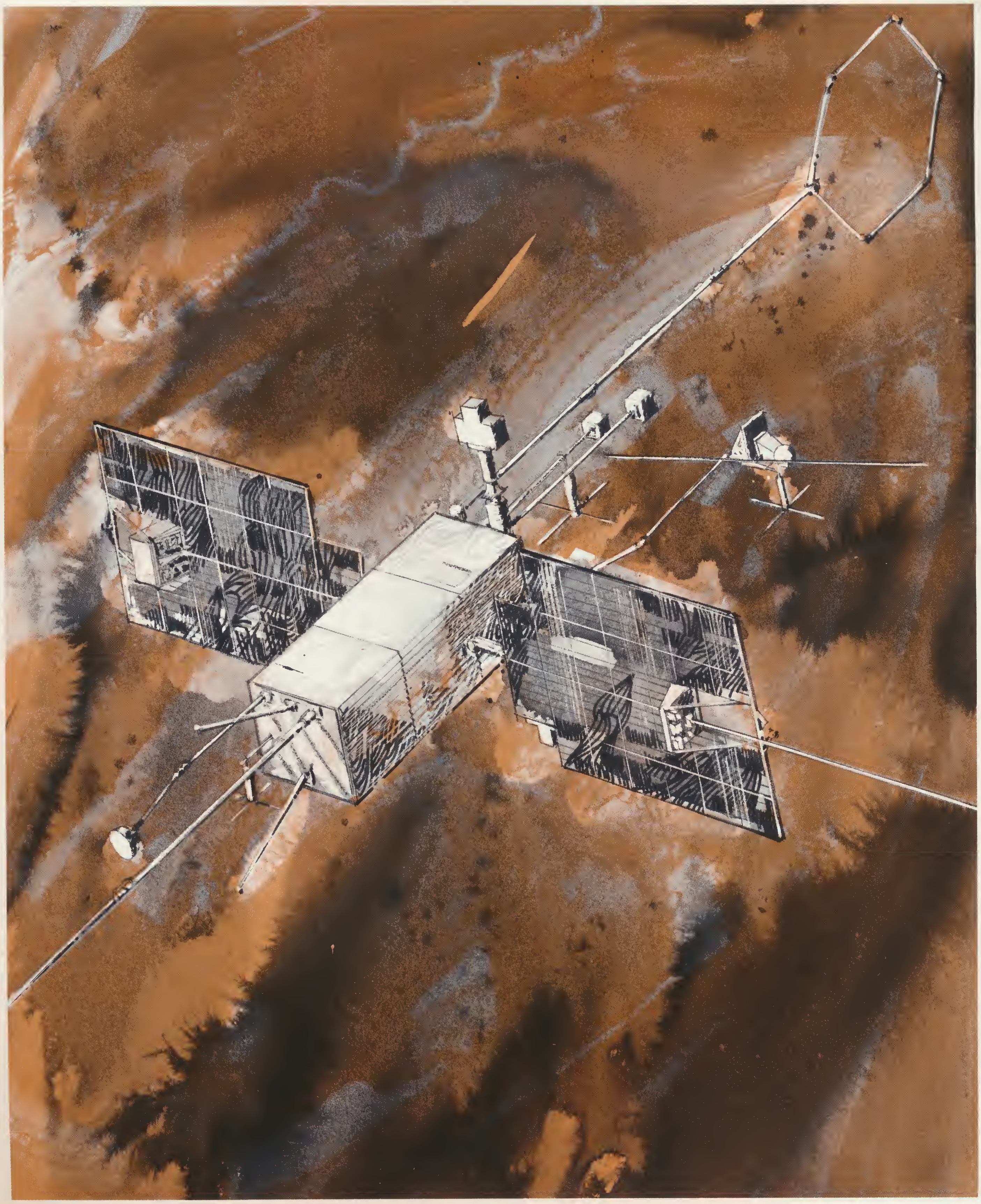
Pioneer V

Pioneer V was the first spacecraft to probe deep into interplanetary space. Launched in March 1960, Pioneer V entered a solar orbit between the orbits of Venus and the earth. Its experiment payload included instruments for studying the solar wind, interactions between the solar wind and the earth's Van Allen region, radiaton levels in interplanetary space, and the interplanetary magnetic field. The spacecraft also carried the first integrated tracking-telemetry-command subsystem and the first space-borne digital computer.

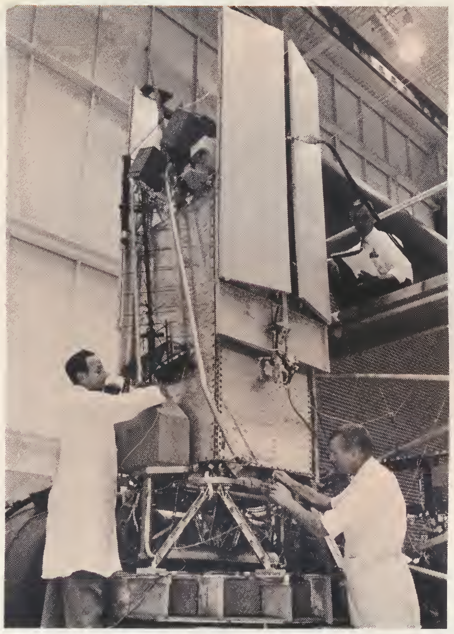
In addition to providing valuable information about a vast unexplored region of space, the Pioneer V mission made it possible for scientists to calculate more accurately the astronomical unit (AU) and true size of the solar system.

On June 26, 1960, three months after launch, a transmission was received from Pioneer V across a distance of more than 22 million miles—establishing a record in long-distance communications that stood for more than two years.

TODAY'S ASSIGNMENTS



Orbiting Geophysical Observatories



The Orbiting Geophysical Observatories are large scientific spacecraft designed and manufactured by TRW Systems for NASA's systematic study of the earth and its space environment. Based on a design concept of a spacecraft as a universal, highly standardized container for orbiting many experiments simultaneously, the OGO gathers vast quantities of scientific data needed to fill important gaps still remaining in our understanding of the earth and its physical environment.

The OGO carries up to 50 scientific experiments and operates in orbit for periods of one year or more. Highly flexible in design, it can be launched into many different types of earth orbits without major structural changes. The OGO's unusually large carrying capacity, long lifetime in orbit, and adaptability for a wide variety of missions make it one of the most economical tools for space exploration yet developed.

A unique feature of the OGO is its ability to orient scientific experiments in five directions: toward and away from the earth, toward and away from the sun, and along the plane of orbit. This allows the experiments to investigate and correlate many different kinds of phenomena occurring in space at the same time. For example, while some experiments are observing changes in solar activity and the solar wind, others can observe related changes that may be occurring in the ionosphere and upper atmosphere.

The OGO transmits scientific data to earth at rates up to 64,000 bits per second and stores up to 86,000 bits of scientific and housekeeping information for delayed transmission. The spacecraft responds to both digital and tone commands and is capable of acting on as many as 269 different instructions.

The first OGO was launched in September 1964 into an orbit with a perigee of 245 miles and an apogee of 94,000 miles — through a cross-section of the earth's space environment ranging from the upper atmosphere to well beyond the outer limits of the Van Allen region. Its payload included 20 experiments designed for investigation of solar flares, atmospheric composition, magnetic fields, cosmic rays, and other phenomena. OGO-II, launched in October 1965, carried 20 experiments into a polar orbit 977 miles at its high point and 310 miles at its low point; and OGO-III, launched in June 1966, carried 21 experiments into an orbit with an initial perigee of 147 miles and an apogee of 65,846 miles. At the time of the OGO-III launch, OGO-I had provided approximately 150,000 experiment hours and OGO-II had provided 45,000 experiment hours. Three additional OGO launches are planned for the NASA series.

Major Subsystems

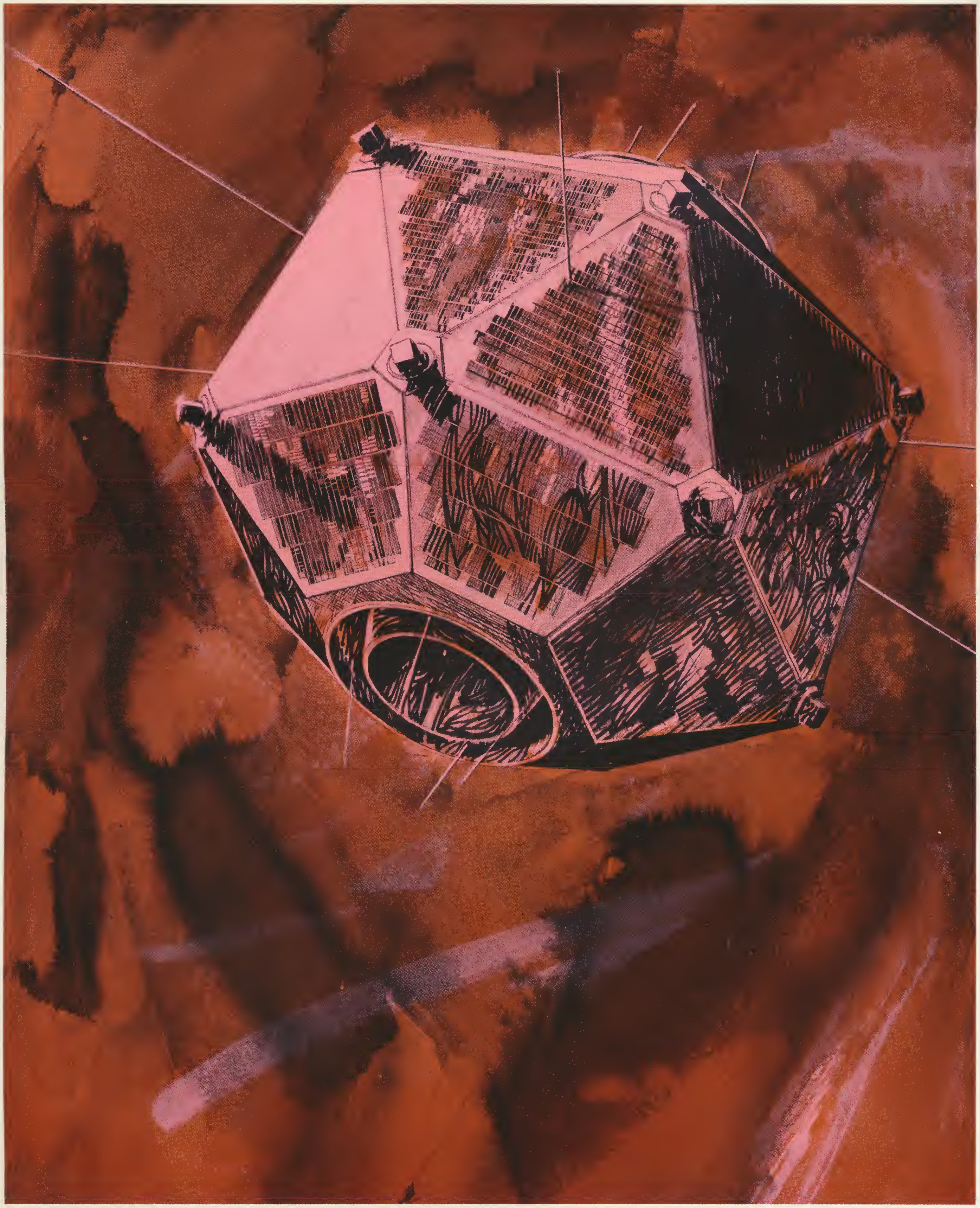
STRUCTURE — OGO is a rectangular structure approximately 6 x 3 x 3 feet in size, from which solar panels, booms, and other appendages are deployed in orbit. Weight, including experiments, is approximately 1,000 pounds. Length from boom-tip to boom-tip is 54 feet. Experiments are carried in the main body and in packages mounted on the solar panels and booms.

ATTITUDE CONTROL — Horizon scanners, sun sensors, and a gyroscope system sense the spacecraft's orientation with respect to the earth, sun, and orbit plane. A pneumatic system and reaction wheels position the spacecraft's main body so that one side always faces the earth and two sides (those from which solar panels project) remain parallel with the line of sight to the sun. Drive mechanisms rotate the solar panels to the proper angle and position boom-mounted experiments packages which are oriented with respect to the orbit plane.

COMMUNICATIONS AND DATA HANDLING — Redundant 100-milliwatt transmitters handle normal tracking requirements; an additional 10-watt transmitter handles tracking requirements on missions reaching distances greater than 60,000 miles from the earth. Redundant digital decoders and a tone decoder handle up to 254 digital and 12 tone commands. The PCM/FM telemetry system, which includes two data-handling units and two 400-mc transmitters, accepts analog or digital signals, makes analog-to-digital conversions, encodes, formats, stores, and transmits in real time or from storage. A "flexible format" allows the sampling of selected experiments at faster than normal rates when space phenomena of special interest occur.

POWER SUBSYSTEM—The OGO's solar array contains more than 32,000 cells which supply 500 watts for recharging two 20 ampere-hour batteries. A 28-volt main bus supplies primary power; dc-dc converters supply special voltages to equipment and experiments.

THERMAL CONTROL—All sides of the spacecraft which face the sun are insulated by multiple layers of aluminized mylar. Thermal louvres are mounted on the two sides from which the solar panels project; the louvres open and close automatically to regulate internal temperatures. Heaters maintain proper temperatures for equipment and experiments.



·r Detection Satellites

The Nuclear Detection Satellites are sentries equipped with ultra-sensitive instruments for detecting nuclear explosions in space. Their mission is to detect violations of the Nuclear Test Ban Treaty signed by the United States, Russia, and more than 100 other nations in late 1963. The treaty prohibits nuclear testing in the atmosphere, under the sea, and in space.

Designed and manufactured by TRW Systems for the U.S. Air Force, the 500-pound satellites can detect clandestine explosions occurring even beyond the orbits of Mars and Venus. Their payloads of instruments–X-ray, gamma, and neutron detectors – are supplied by the Atomic Energy Commission. To guard against the possibility that an explosion will go undetected because it occurs on one side of the earth while a satellite is on the other, the Nuclear Detection Satellites are launched two at a time and maneuvered into position on opposite sides of the earth.

Six Nuclear Detection Satellites were launched between late 1963 and mid 1965. As of July 20, 1965, the date on which the fifth and sixth satellites were launched, the first pair had been functioning continuously for more than three times the specified design lifetime. In June 1966, the combined orbital operation for the six satellites totaled more than eight years.

Original program plans called for the launch of five pairs of developmental satellites to fully evaluate the launch technique and performance. However, the first launch was so successful, it was possible to reorient the entire program —accelerating it by a full year and resulting in savings of 26 million dollars.

An intricate three-part launch and injection technique is used to position the satellites in orbit. First, two satellites are tandem-launched into a wide-ranging elliptical orbit. Next, as they reach the high point of the orbit for the first time, one is injected into a circular orbit. Then, after the remaining satellite has completed another orbit and reaches the high point for the second time, it too is injected into a circular orbit. These maneuvers position the satellites at an altitude of approximately 60,000 miles, spaced 180 degrees apart.

TRW Systems was awarded a follow-on contract for larger and still more sophisticated Nuclear Detection Satellites. As in the previous contract, the company is performing under an incentive agreement whereby its earnings are tied directly to a series of performance criteria.

Major Subsystem

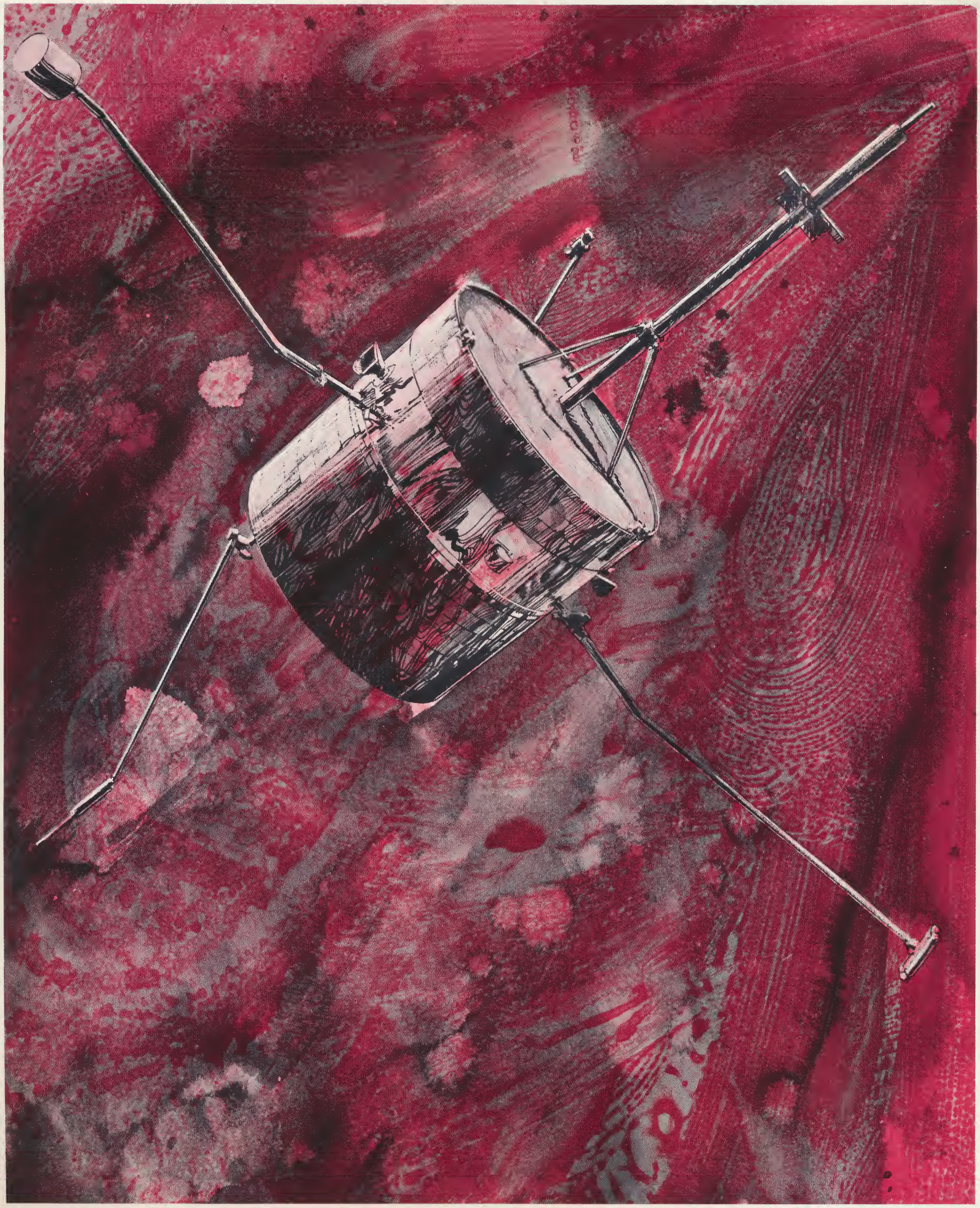
STRUCTURE — The satellite is a 20-sided symmetrical structure (icosahedron) about five feet in diameter and 500 pounds in weight. A central cylinder houses a solid-fueled injection engine. Spacecraft equipment and some of the AEC detectors are mounted on an internal platform. The remaining AEC detectors are carried in the 18 external apex fittings. An interstage structure links each pair of satellites for launch. The interstage includes a cold gas system for spin up of the satellites before separation.

COMMUNICATIONS AND DATA-HANDLING — Communication equipment is designed for ranges up to 75,000 miles. Two data storage units provide a capacity for 60,000 bits of scientific and housekeeping information. Up to 90 different types of data can be processed and transmitted to the ground in real time or from storage.

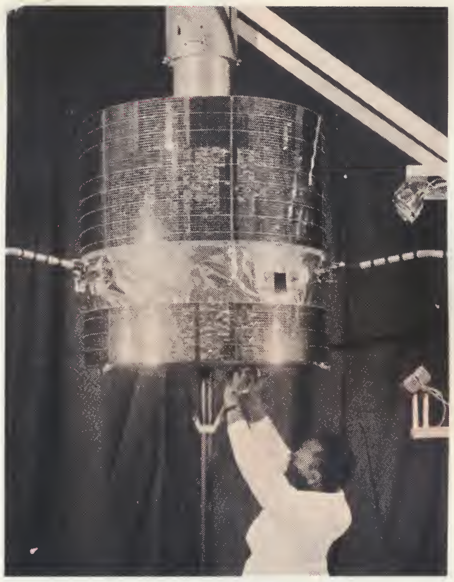
ELECTRICAL POWER — 13,326 solar cells mounted on 18 faces of the spacecraft provide 90 watts of electrical power. Two rechargeable nickel-cadmium batteries supply 75 watts during eclipses.

THERMAL CONTROL — Provided by passive means.

VELOCITY CONTROL AND ATTITUDE ORIENTATION—The latest versions of satellites contain a velocity control and attitude reorientation subsystem consisting of a sun sensor, small thrusters, and control equipment. The subsystem makes velocity adjustments to maintain proper spacing between the satellites in orbit, and orients the spin axis of each satellite perpendicular to the sun line, thus assuring maximum solar cell output.



The Pioneers



Pioneer 6, launched in December 1965, is the first of a new series of deep space satellites designed and produced by TRW Systems for NASA. The new Pioneers will explore the vast region of space man must cross to reach Mars and Venus. A major objective of the Pioneer program is to gain a better understanding of how the sun's tremendous outpouring of X-rays, gamma rays, atomic particles, and other forms of energy affects the space environment. The Pioneers will also make precise measurements of the sun's magnetic field, gather new information about cosmic dust, and participate in a series of spacecraft-to-ground radio propagation experiments.

The Pioneers are launched into elliptical orbits around the sun. The orbit of Pioneer 6 is carrying the spacecraft inward, toward the orbit of Venus, to a perihelion of 73 million miles—20 million miles closer to the sun than the earth. Another orbit will carry a Pioneer outward, toward Mars, to an aphelion of 110 million miles—17 million miles beyond the earth's orbit. Still other Pioneers will be launched into approximately the same orbit as the earth, but leading or lagging our planet by several million miles.

The Pioneers are drum-shaped structures about 37 inches in diameter and 35 inches high. Weight, including deployable booms and a full payload of experiments, is 140 pounds. Communications equipment transmits to earth across distances as great as 40 million miles—almost half the distance between the earth and sun.

In flight, the Pioneer is spin-stabilized and oriented with its spin-axis perpendicular to both the sun and the earth. Spinning the spacecraft allows its experiments to observe solar phenomena through a complete 360-degree field of view. Orientation with the sun and earth allows the spacecraft's solar array to receive a maximum amount of sunlight, and its communication antenna to radiate a maximum amount of energy to NASA ground stations.

Because the Pioneers will make ultra-precise measurements of the sun's magnetic field, special precautions have been taken to assure that they are the cleanest spacecraft, magnetically speaking, ever launched. Careful selection of materials and use of special design and manufacturing techniques permit the Pioneers to make these measurements to an accuracy of one gamma — about one fifty-thousandth of the strength of the earth's magnetic field at its surface.

Major Subsystems

STRUCTURE—Pioneer is a cylindrical structure equipped with three deployable booms, an external communication antenna, and an external experiment antenna. Equipment and some experiments are carried on a cylindrical platform inside the main body. One of the booms carries a magnetometer experiment; a second is fitted with a gas nozzle; the third carries a wobble damper used for stabilization.

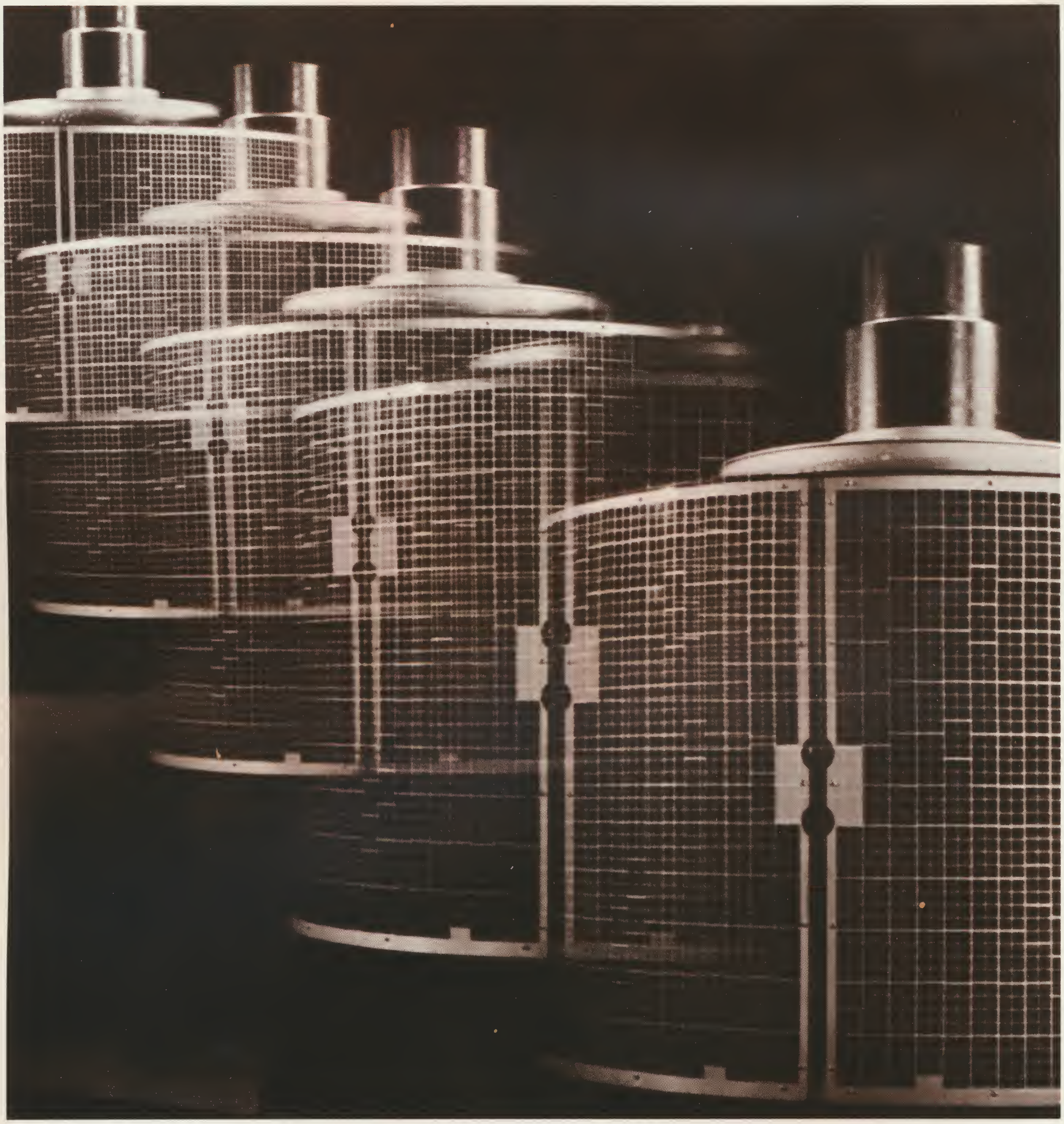
COMMUNICATIONS AND DATA-HANDLING — Pioneer communicates on S-band with DSIF stations across distances up to 40 million miles. A command distribution unit handles up to 60 commands — can be expanded to handle 80 commands. A digital telemetry unit accepts inputs in analog or digital forms, makes analog-to-digital conversions, transmits in four different formats selected by ground command, and is capable of five different bit rates ranging from 8 to 512 bits per second. A data storage unit stores up to 15,232 bits, equivalent to 68 frames of scientific data.

ORIENTATION — The spin-stabilized spacecraft is oriented by two separate maneuvers: one to place the spin-axis perpendicular to Pioneer's line of sight to the sun, and a second to place the spin-axis perpendicular to the earth's ecliptic. The orientation subsystem includes five sun sensors; a pneumatic system, including a boom-mounted gas nozzle; and associated electronics. Four of the sun sensors provide signals for orienting the spacecraft about two axes; the remaining sensor acts as a sun reference for experiments.

ELECTRICAL POWER — Pioneer's electrical power subsystem includes a cylindrical solar array, a rechargeable secondary battery, and high- and low-voltage converters. The solar array provides up to 60 watts of power; experiments are supplied directly from a 28-volt main bus.

THERMAL CONTROL — The spacecraft main body is thermally insulated except for a cylindrical area at one end, which is fitted with thermal louvres. Control for the solar array, antenna, and boom-mounted packages is passive.

SATELLITES FOR COMMUNICATIONS



TRW Systems has been active in the analysis, research, and design of communications satellites since 1958. It developed the basic system concepts and design of surface-station/satellite networks for the Air Force's Steer, Tackle, and Decree programs and for the Army's Advent program. On Project Score, TRW helped establish in orbit the first earth satellite to accept voice communications and relay them back to earth. TRW provided overall technical assistance for Project Courier, together with the design of the booster configuration and trajectories for the Courier program. The company provided systems engineering and ground-station hardware for the NASA's Relay experimental satellite, and it designed and built range and range rate equipment for the Syncom program.

TRW's design efforts for the Minimum Essential Survivable (MESU) communications satellite and the Medium Altitude Communications System (MACS) led to an Air Force contract for the development of Military Communications Satellites. TRW has conducted a wide-range of studies for the Advanced Defense System Communications Program (ADSCP), including investigations of gravity-gradient stabilization and advanced techniques in modulation and data handling. In August 1965, TRW completed a six-month engineering design study for a medium altitude, phased system of satellites for the Communications Satellite Corporation (Comsat).

Today, TRW Systems performs a major role in the development and manufacture of advanced satellites and systems for both military and commercial communications.

Global Communications Satellites

TRW Systems, together with an international team of subcontractors, is designing and building satellites for the first Global Communications System, which is being established by the Communications Satellite Corporation (Comsat) as manager for the International Telecommunications Consortium.

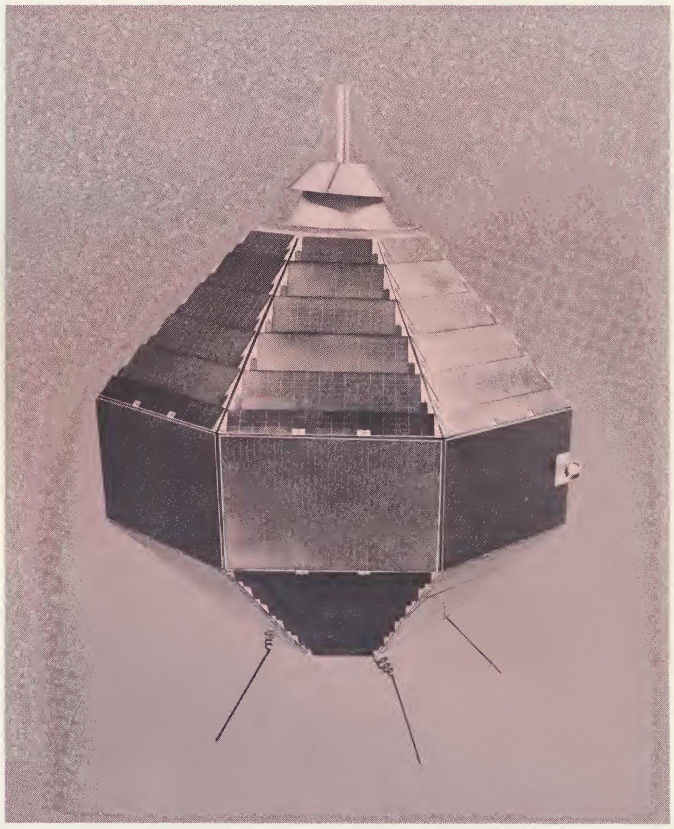
The TRW satellite is a lightweight, highly reliable spacecraft which can be operated in a 24-hour synchronous orbit (22,300 miles) or in 8-hour or 12-hour medium altitude orbits. Its wideband repeater system includes two 225-mc transponders which provide more than 1500 two-way telephone channels, or four television channels simultaneously. The satellite has a minimum lifetime of five years.

The satellite is a cylindrical structure 56 inches in diameter and 37 inches high, weighing 233 pounds. It will be spin stabilized with its spin axis perpendicular to the plane of orbit. Its high-gain, direction antenna is controlled by an electronic "despinning" technique: as the satellite spins, the antenna's beam is rotated at the same rate in the opposite direction to keep it focused on the earth.

The satellite carries earth sensors and a sun sensor which provide attitude and rotational data to the ground. Earth stations control the satellite's orbital position and orientation by commanding axial and radial thrusters contained in the satellite's monopropellant hydrazine system. Primary power is provided by a fixed, body-mounted solar cell array. A battery supplies power to the satellite during eclipses.

Military Communications Satellites

To provide the U.S. Air Force with a worldwide communications system, TRW Systems is teamed with the Philco Corporation in the design and manufacture of a series of Military Communications Satellites. These lightweight, reliable spacecraft are designed for multiple launch into a number of different orbital planes to satisfy specific military requirements. TRW's role in the program includes the development and manufacture of spacecraft structures and power subsystems.



The satellite structure consists of an octagonal center section and top and bottom sections formed as truncated eight-sided pyramids. The body-mounted solar array provides up to 30 watts of power which is regulated and distributed to the subsystems by the TRW-designed power control unit.

Spin stabilization of the satellite is accomplished by two external nozzles fed from a sphere in the center of the structure. Mechanical and electrical design assure that all possible sources of magnetic disturbance in the spacecraft are reduced to an absolute minimum. Thermal control is maintained through the use of coatings and the careful placement of subsystems within the structure.

TRW's participation as major subcontractor on the Military Communications Satellite program includes incentive provisions which make company profits dependent upon hardware costs and delivery and upon satellite operation and lifetime.

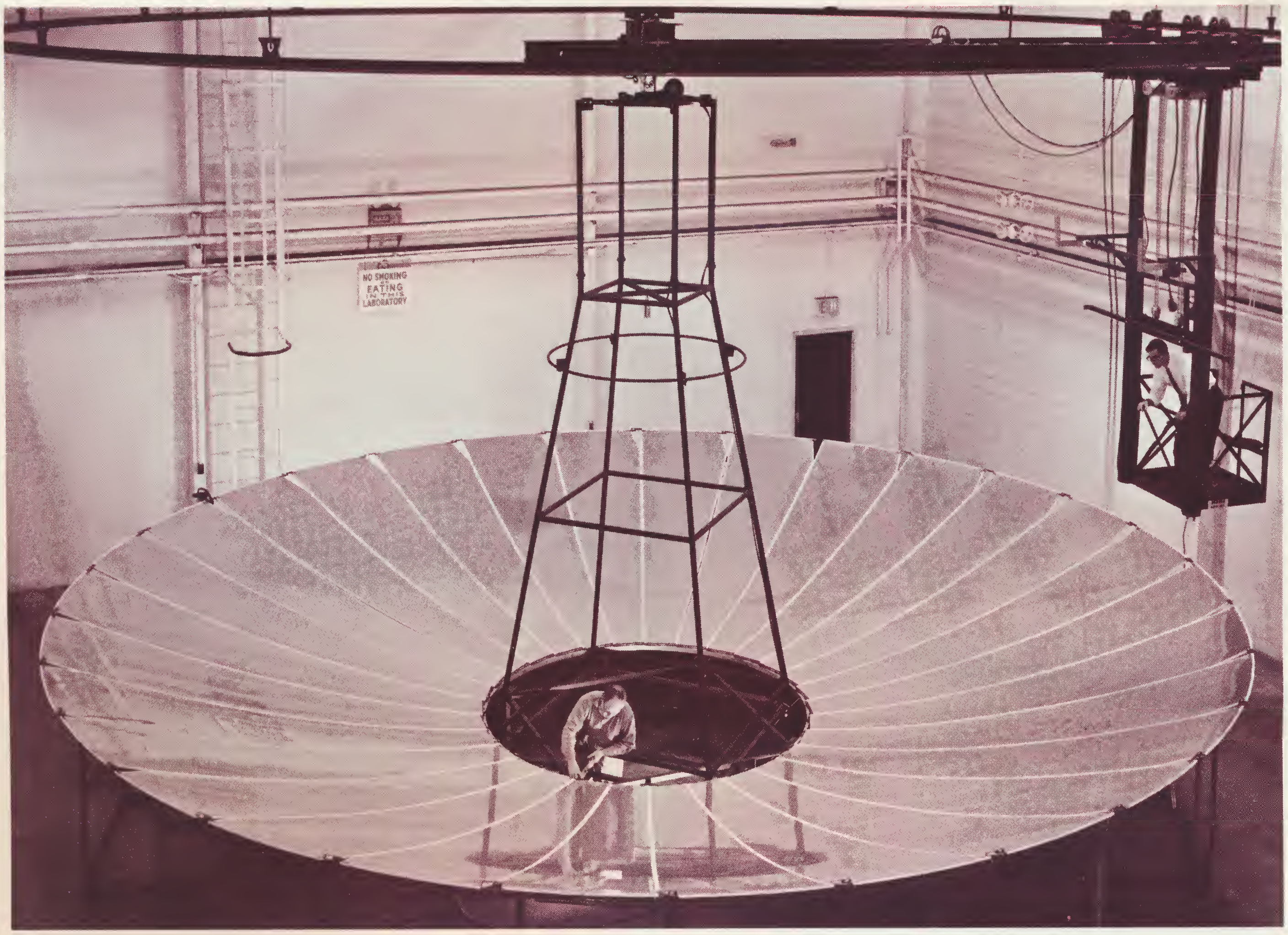
Environmental Research Satellites

TRW's Environmental Research Satellites are a family of piggyback spacecraft developed for low-cost missions and experiments in space. They range in weight from 1.5 to 30 pounds, and can be attached to boosters of larger spacecraft without appreciably affecting thrust requirements. Their low cost per pound in orbit and short lead time (3 to 6 months) make the ERS ideal vehicles for component testing, space environment experiments, range calibration, sensor testing, and many other kinds of scientific and technological missions. They have been proven on several different programs; as of January 1966, TRW has built or has under development contract a total of 27 ERS.

The ERS family includes tetrahedral-shaped satellites (TRS) weighing from 1.5 to 7.6 pounds and octahedral-shaped satellites (ORS) weighing from 5 to 30 pounds. The satellites are self-contained; a single-point attachment and separation mechanism is the only link with the primary vehicle. All are equipped with solar cell electric power systems and standardized, flight-proven telemetry systems. Many are also equipped with command receivers, rechargeable secondary batteries and subsystem capabilities such as stabilization, data storage, and sun angle sensing.

The ERS can be inserted into orbit with a wide range of spin rates or low acceleration environments, depending on the specific experiments being conducted. TRW Systems provides support services for the satellites missions, including experiment design and integration, launch integration, and data reduction and analysis.

The first tetrahedral satellite, TRS-1, was launched in September 1962 as part of a classified Air Force space mission. The satellite gathered data on solar cell damage caused by radiation in the Van Allen region. The success of the TRS-1 missions led to the development of the ERS family and to a wide variety of space experiments performed by both tetrahedral and octahedral satellites. In July 1965, an ORS-III was placed into a highly elliptical orbit (200-mile perigee and 65,000-mile apogee) by the Atlas-Agena, which had as its primary mission the orbiting of two TRW Nuclear Detection Satellites. The ORS-III carried several nuclear detectors for electron, proton, and gamma-ray measurements.



TRW personnel are preparing for the space projects of the next decade and beyond, including: development of advanced, multi-purpose satellites for weather prediction, navigation, and communications; landing of a large, instrumented capsule on Mars; scientific probes to the outer planets; manned landing and fly-by missions to Mars and Venus; out-of-the-ecliptic missions; and solar system escape missions.

In anticipation of tomorrow's challenges, TRW is conducting an unusually diversified, company-funded research and development program in fields ranging from nuclear technology, lasers, and applied mathematics to conceptual studies of new types of manned and unmanned spacecraft. Following are a few examples:

Exploration of Mars

TRW is playing a vital role in our country's continuing program to explore Mars. In addition to its work as major subcontractor on the Mariner missions, TRW has performed extensive studies for the Voyager program, including spacecraft design studies under contract to NASA. The unmanned Voyager will gather scientific data on the physical environment, atmospheric composition, and surface features of Mars. The mission involves the insertion of a spacecraft into orbit around the planet, and the landing of large instrumented capsules. A possible TRW configuration consists of a spacecraft and capsules weighing approximately 17,500 lbs., including the retropulsion system. The propulsion module will use major portions of the Lunar Excursion Module descent stage which is being produced by TRW for the Apollo program.

The "Flying Antenna"

TRW has completed conceptual studies of a scientific spacecraft for missions to the outer planets—including Pluto, the most distant planet from the sun.

A major feature of the spacecraft is the use of a large, deployable parabolic antenna to greatly increase communication ranges. The antenna design is based on a sunflower parabolic reflector originally developed by the TRW Equip-

ment Group for use as a solar energy collector in space power applications. Of petulous design, the reflector stows with its petals upward, and unfolds like an umbrella.

The proposed spacecraft is flexible enough in design for use in fly-by probe, orbiter, or planetary landing missions. Electric power would be provided by SNAP type nuclear generators.

TRW engineers estimate that a 10-watt transmitter aboard a spacecraft equipped with a 16-foot sunflower antenna will relay scientific information to earth at rates of 400 to 1000 bits per second from Jupiter's orbit, and 8 bits per second from a portion of Pluto's orbit. A 210-foot DSIF antenna on earth would be used to maintain communication with the spacecraft.

Orbiting Space Antennas

TRW has developed a concept for erecting giant space antennas which will orbit the earth above the ionosphere to gather radio astronomy data at frequencies which cannot be received by ground-based observatories. The TRW design consists of a lightweight spacecraft and a spin-deployed filamentary antenna net. The antenna is wound on a reel that is a structural part of the spacecraft.

In orbit, the antenna unreels from a small central hub using a self-governing technique that requires no controls. The concept is adaptable to various size antennas to cover the range of frequencies below 1 megacycle. Antenna structures with diameters of 400,000 feet are planned for gathering data at frequencies as low as 50 kilocycles.

The spacecraft will carry experiment and communications equipment for relaying previously unobtainable information about radio sources, galactic structure, and quasars.

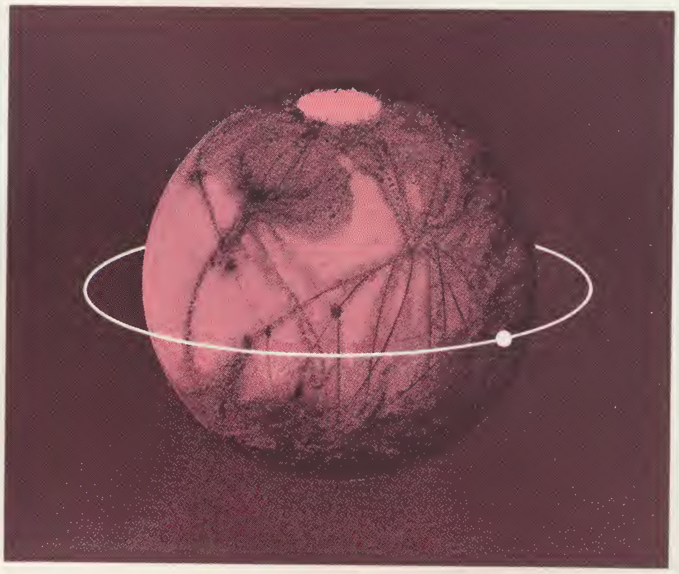
Orbiting Infrared Sky Mapper

TRW personnel are working closely with astronomers and scientists from several universities to develop an Orbiting Infrared Sky Mapper which will obtain information on the infrared portions of the sky which cannot be detected by optical or radio telescopes.

The TRW concept envisions a spacecraft of less than 400 pounds which will carry infrared sensors into orbit and scan the entire sky in a period of six months. The spacecraft is spin stabilized with the spin axis in the direction of the sun line. A large thermal shield on the sun side of the spacecraft protects the sensors and optical instruments which are immersed in liquid helium to maintain the required cold temperatures.

Multi-Purpose Satellites

TRW engineers are engaged in the development of multi-purpose satellites which combine the functions of many missions into one spacecraft or one launch operation. The effective integration of multiple space payloads into one



vehicle provides maximum use of launch capabilities at substantial savings in costs. Efforts at TRW include the combining of such functions as early-warning detection, meteorology, nuclear detection, communications, and navigation. Missions which have similar orbit and reliability requirements are being combined into TRW spacecraft, and several studies are underway to expand the multi-purpose satellite concept. Design studies include a multi-purpose communication satellite which combines simultaneous television, telephone, and data transmission with aircraft-to-ground and ship-to-shore communications.

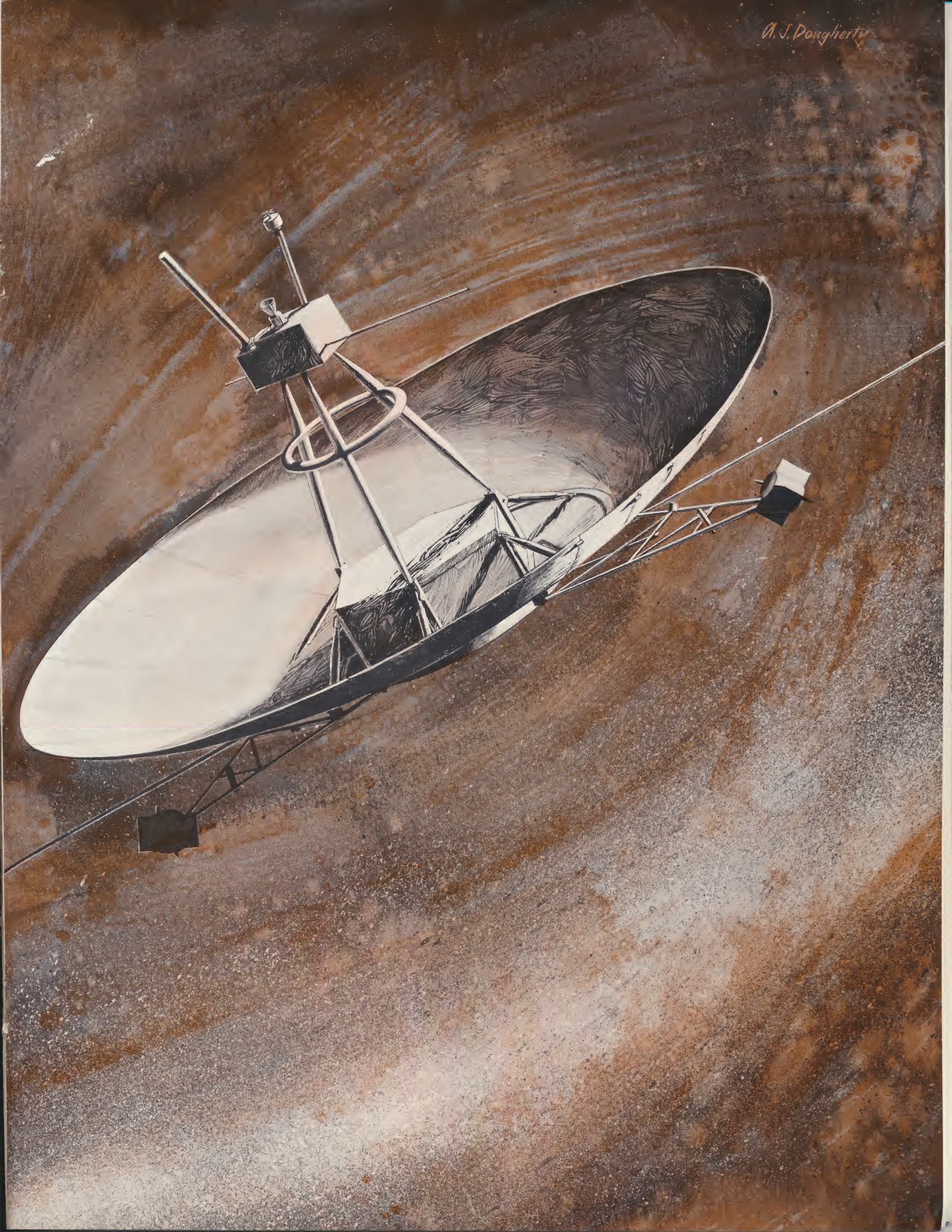
Electrical Power Systems

TRW is developing new techniques for providing the increased amounts of electrical power needed for large orbiting space stations, new generations of communications satellites, and missions to the outer limits of the solar system.

The objective of one study program is to develop large, lightweight solar arrays weighing a pound or less for every 20 watts of power delivered. Included are investigations of new types of solar cells (e.g., single-crystal and thin film cells), new techniques for fabricating modules and panels, and the development of conceptual designs for lightweight arrays capable of delivering as much as 30 kilowatts of power.

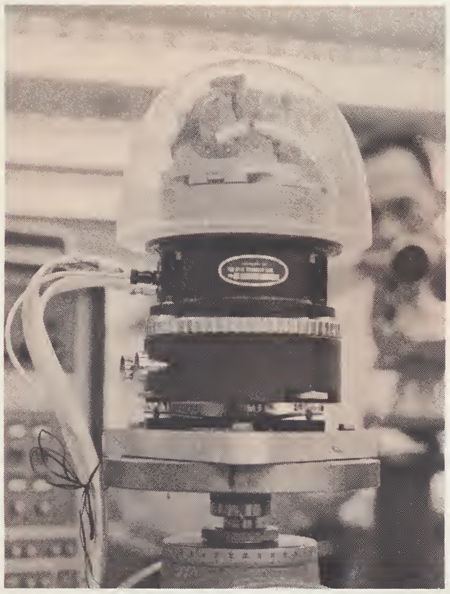
TRW is also investigating advanced techniques in nuclear power conversion, including magnetohydrodynamic conversion, in which electricity is generated by passing a conductive fluid or gas through a strong magnetic field. Studies include the investigation of methods for utilizing highly conductive plasmas and liquid metals as working fluids, and the generation of ultra-high magnetic fields. A basic objective of TRW's studies in nuclear power conversion is the development of AC and DC systems in the 3 to 30 kilowatt range.

PLUTO ORBIT
NEPTUNE ORBIT
URANUS ORBIT
SATURN ORBIT
JUPITER
EARTH ORBIT
VENUS ORBIT
MERCURY ORBIT
MARS
SUN


A. J. Dougherty

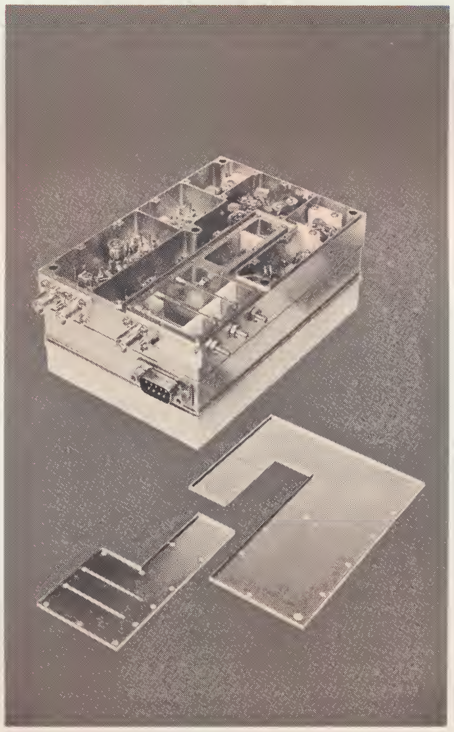
OUR TECHNOLOGICAL BASE

Guidance and Control



TRW personnel have participated in the development of inertial and radio guidance systems for three generations of Air Force ballistic missiles...trajectory analysis and the formulation of guidance equations for a wide variety of earth-orbiting, lunar, interplanetary, and manned flights–including NASA's Ranger, Mariner, Mercury, and Gemini missions...and the design and fabrication of complete stabilization and control subsystems for almost a dozen different types of spacecraft. Among other current assignments, TRW is engaged in trajectory analysis for Project Apollo. Company personnel are developing the Abort Guidance Section, a strapped-down inertial guidance system which will be used as a backup for primary guidance equipment of NASA's Lunar Excursion Module. Other activities range from the design and fabrication of components such as sun sensors, earth sensors, and precision gyro systems . . . to advanced research in fields such as man-machine relationships in guidance and control.

Spaceborne Communication Equipment



TRW Systems delevoped the first integrated telemetry, tracking, and command system for Pioneer I and has continued to build and improve communication systems for satellites and deep-space vehicles. The Space-Ground Link Subsystem (SGLS) is a standardized, S-band telemetry, tracking, and command system designed and built by TRW for the Air Force Space Systems Division. Its modular design provides a range of space communication functions never before available in a single subsystem. Pioneer VI's integrated S-band system, designed by TRW for deep-space communications, is providing two-way transmission with NASA ground facilities at distances of more than 40 million miles. TRW facilities include modern experimental laboratories for the design and testing of space communication systems, controlled-environment fabrication and assembly areas, and a fully instrumented antenna test range.

Ground-Based Communication Equipment

TRW designed and installed the first worldwide network of tracking stations used in the nation's space program. Called SpaN, the network included ground stations in California, Florida, England, Singapore, and Hawaii. TRW personnel produced mobile ground stations for the Transit and Courier launches, a range and range rate system for the Syncom program, mobile stations for the OGO program, two ground test stations for Project Relay, and angle tracking receiver for the French Government, FM wideband receivers, parametric amplifiers, and a wide range of electronic subsystems. The company's role in the Air Force's SGLS program includes the design and manufacture of standardized, S-band ground equipment for telemetry, tracking, and command of manned and unmanned space vehicles.

Propulsion

TRW designs and manufactures a variety of fixed-thrust, throttleable, and pulse-modulated rocket engines for powering and controlling upper stage vehicles and spacecraft. Current assignments include the design and manufacture of two types of engines for NASA's Project Apollo: a deep-throttling descent and landing engine for the Lunar Excursion Module (LEM), and a pulse-modulated bipropellant reaction control engine for the S-IVB stage of the Saturn V launch vehicle. The man-rated LEM descent engine delivers up to 10,500 pounds of thrust and has a throttle range of 10:1. TRW personnel are performing long-range research and development projects in chemical, electrical, and nuclear propulsion. They are developing a radioisotope-powered monopropellant hydrazine engine (NIMPHE) capable of unlimited restarts, a hydrogen-fueled radioisotope engine (POODLE) with specific impulse in the 700-800 range, and a combination radioisotope thruster and electric power source (SNAPOODLE).

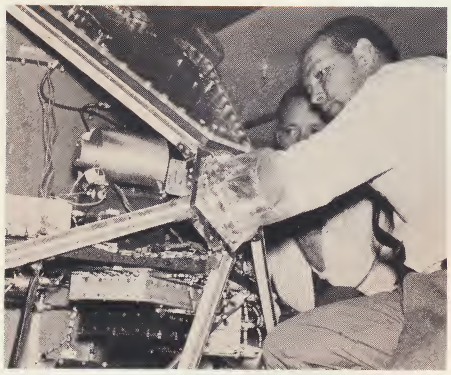
Electrical Power Systems

TRW's experience in electric power ranges from materials and components evaluation to the design and fabrication of complete spacecraft power systems. TRW has designed and manufactured battery systems for missiles and spacecraft since 1957. At its modern Battery Test Facility, the company is working on nickel-cadmium, silver-cadmium, and silver-zinc battery systems with operational lifetimes of more than two years under temperature ranges of −20°C to +75°C. TRW is one of the nation's few suppliers equipped for the serial production of large solar cell arrays. The array produced for Orbiting Geophysical Observatories contains 32,256 cells with a total power output of 714 watts. Advanced research in electrical power at TRW includes studies of new techniques and equipment for power conditioning and control, and projects in fields such as thermionic, thermoelectric, electrohydrodynamic, and magnetohydrodynamic power conversion.

Microelectronics

TRW's microelectronics center provides direct support of the company's space hardware development programs. Microelectronics specialists collaborate closely with the systems designers so that new circuit techniques can be applied efficiently and economically to actual flight equipment. Thin film projects include the development of superconducting thin films, the investigation of nonlinear electron transport in thin films, and the development of materials and fabrication techniques for both active and passive microcircuit components. The company has designed and built a wide range of microminiaturized hardware, including: S-band receivers that incorporate thin-film, integrated, and hybrid circuits, and completely microminiaturized PCM telemetry units and general-purpose programmers. Company research programs have demonstrated that analog circuits for spacecraft guidance and control systems can be constructed using hybrid microelectronic techniques, i.e., combinations of integrated circuits and thin-film networks.

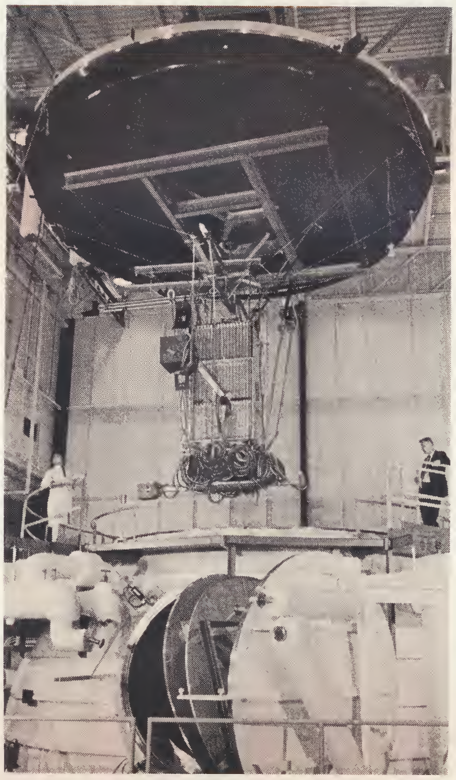
Experiment Integration



TRW plans, constructs, and interprets space physics experiments in magnetic fields, charged particles, and radio propagation effects, using instruments designed and built in its own laboratories and shops. On major spacecraft programs—such as the OGO which can carry up to 50 different experiments—TRW acts as coordinator and systems manager for integrating the experiments of various other agencies. In addition to anticipating and solving experiment interface problems in the design and fabrication of spacecraft, TRW provides a variety of services to experimenters, including: definition of data transmission requirements and trajectory and how they affect experiment design; definition of experiment interface requirements; furnishing of laboratory facilities and assistance in bench tests, calibration, and servicing; and field engineering services at the launch site. Since 1958, TRW has performed experiment integration on:

Year	Spacecraft	Number Space-craft	Number Experi-ment
1958-1960	Able I, IV, Va, Vb	4	28
1958	Pioneer I, II	2	9
1959	Explorer VI	1	8
1961-1966	OGO A, C, D, E	4	84
1961-1966	Nuclear Detection Sat.	6	120
1962-1966	ERS	27	28
1963-1966	New Series Pioneers	4	24
	Total	48	301

Environmental Testing



The TRW Environmental Test Laboratory is capable of subjecting spacecraft and their components to extreme conditions of temperature, humidity, vacuum, and simulated solar radiation. A 30-foot spherical space environment chamber permits thorough evaluation of complete spacecraft or individual subsystems prior to flight. This chamber will produce a vacuum equivalent to an altitude of about 700,000 feet, and use of liquid or gaseous nitrogen makes it possible to produce temperatures from −315°F to +275°F. Solar simulation is provided for a target area 7 feet in diameter at intensities of 65 to 130 watts per square foot (one-half to one sun). The laboratory also has a variety of high-vacuum chambers, altitude chambers, temperature-humidity chambers, portable heat exchanger units, and other test equipment.

Thermal Control

Very few organizations have depth and breadth of experience TRW Systems has demonstrated during the past ten years in thermal control of spacecraft and ballistic missile systems. TRW scientists and engineers are skilled in all thermal control disciplines, including the analysis of temperature characteristics of electrical components and propulsion units, studies of thermal properties of materials used in spacecraft manufacture, and the design and development of thermal control components such as heaters and thermal louvers. Company personnel are conducting a wide range of advanced research in thermal control techniques such as cryogenic insulation, heat transfer and cooling in high-energy propellant engines, and thermal control during re-entry.

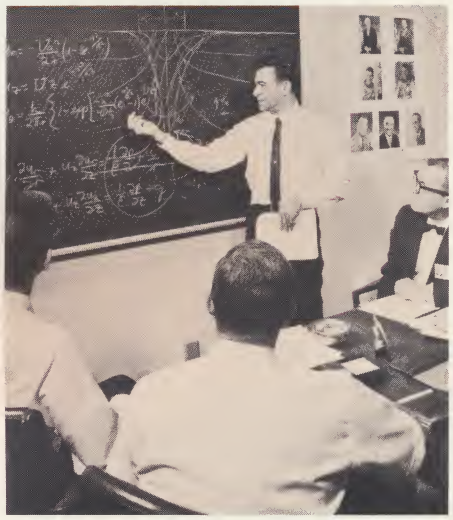
Fabrication

TRW Systems' manufacturing facilities are the nation's first specifically designed for the production and testing of upper stage vehicles and spacecraft. Capabilities range from the fabrication of mechanical piece-parts to the assembly and checkout of complete spaceborne and ground-based system. Facilities include machine and sheet metal shops, plastics and insulation shops, electric assembly areas equipped for operation as Class 10,000 and Class 100 clean rooms, controlled-environment integration and test areas, and specialized areas for activities such as the manufacture of printed circuits, solar array test and calibration, electromagnetic compatibility testing, and the fabrication of microminiaturized circuits. TRW facilities are geared for production to most stringent specifications, including MIL-Q-9858A, MIL-C-45662, and NASA NPC-200-2 and 3.

Launch Support Operations

TRW has provided launch support for almost 400 ballistic missile and spacecraft flights. Its personnel are experienced in all phases of field checkout and launch, including prelaunch testing, integration of spacecraft and booster, countdown, and actual launch operations. TRW also provides post-launch services such as command and control during launch, injection, and orbital operation, and quick-look analysis of telemetry data.

Applied Mathematics



TRW operates one of the aerospace industry's largest data processing centers, staffed by more than 400 personnel skilled in fields such as trajectory analysis, orbit prediction and determination, the reduction and analysis of telemetry data, and advanced management control techniques. In addition to their work in support of current NASA and Air Force space programs, TRW's mathematicians are engaged in a variety of advanced study projects. Typical of these are: the development of new analytical approaches and computational techniques for studying spacecraft motion; the development of on-line computer systems for solving complex problems in the physical sciences; and the development of standardized computer programs for use in fields such as vehicle/ trajectory/ thrust optimization.

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